Line of Action: Concepts & Calculations

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In the past gear manufacturers have had to rely on hob manufacturers' inspection of individual elements of a hob, such as lead, involute, spacing, and runout. These did not always guarantee correct gears, as contained elements may cause a hob to produce gears beyond tolerance limits.

A solution to the individual element inspection is to have a "line of action" inspection that is a composite of all individaul elements, giving absolute assurance that the hob will cut parts to print tolerances (negating machine errors).

The following technical presentation will describe "line of action" and its benefits to the gear producer.

Concepts and Calculations

It is understood that the line of action (generation) is the succession of points of contact between the hob flank and the gear flank during the generation process.

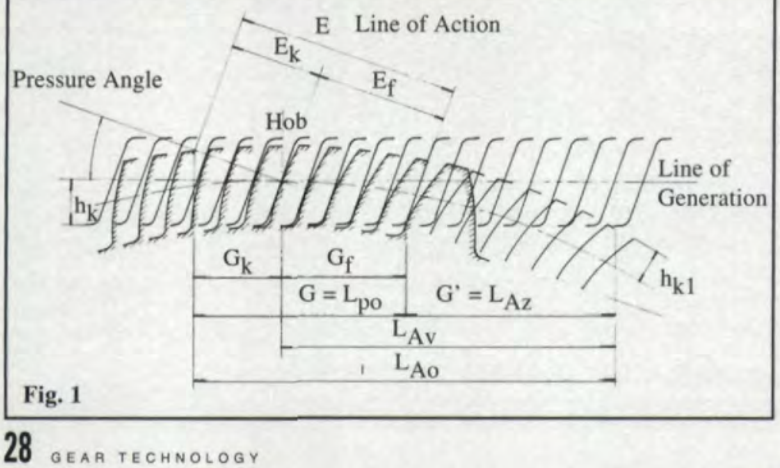

Fig. 1

This line, shown in Fig. 1., is normal (perpendicular) to the hob flank profile and forms with the horizontal line (line of generation), the pressure angle value.

The generation segment (length of action) is the necessary generation length to generate all the involute flank of a gear profile.

According to Fig. 1, we will detail all the values:

Ek = Generation segment of the gear addendum.

Ef = Generation segment of the gear dedendum.

E = Generation segment of the gear tooth involute profile.

Gk = Addendum generation length.

Gf = Dedendum generation length.

G = Profile generation length.

G^1 = Roughing length of the tooth profile.

Calculation formulae:

$$Ek = \sqrt{((d0_v / 2 + h_{kl})^2 - (d0_v / 2 * \cos \alpha n)^2)} - d0_v / 2 * \sin \alpha n$$

$$Ef = \frac{hk}{\sin \alpha n}$$

$$E = Ek + Ef$$

$$Gk = Ek * \cos \alpha n$$

$$Gf = Ef * \cos \alpha n$$

$$G = Gk + Gf$$

$G' = \sqrt{((d0_v / 2 + h_{kl})^2 - (d0_v / 2 - hk)^2)} - Gf$

being:

hk = hob addendum.

h_{kl} = gear addendum

$d0_v$ = normal pitch diameter.

$$d0_v = mn * zv = mn * \frac{Z1}{\cos \beta 01}$$

Z_1 = number of gear teeth

$\beta 01$ = gear helix angle at the pitch diameter

αn = normal pressure angle

So, in this way for a rack limit case ($Z_1 = \infty$):

$$E = \frac{h_{k1}}{\sin \alpha n} + \frac{hk}{\sin \alpha n}$$

$$G = E * \cos \alpha n$$

For a module mn = 1

hk = 1.25

$h_{k1} = 1$

we will have:

$\alpha n = 20° \longrightarrow E = 2.9238 + 2.6548 = 6.5786$

$G = 6.1989$

$\alpha n = 30° \longrightarrow E = 2 + 2.5 = 4.5$

$G = 4.2286$

$\alpha n = 15° \longrightarrow E = 3.8637 + 4.8296 = 8.6933$

$G = 8.1690$

If we divide the length G by the normal lead (tn), we will obtain the necessary hob turns (revolutions) to generate the gear tooth profile.

$$\text{Number of revolutions} = \frac{G}{t_n * Z}$$

being: Z = number of hob threads,

t_n = nominal pitch

So we have:

$\alpha n = 14° 30' \longrightarrow$ 2.86 revolutions.

$\alpha n = 15° \longrightarrow$ 2.6 revolutions.

$\alpha n = 20° \longrightarrow$ 1.97 revolutions.

$\alpha n = 30° \longrightarrow$ 1.346 revolutions.

However, we can say that if we make three revolutions, we will cover all the possibilities for any normal pressure angle.

Checking and Standards

In order to check a hob line of action (generation), we must see the difference between mechanical checking machines and CNC checking machines.

The mechanical checking machines, i.e. Klingelnberg models PWF 250 and 300, have this capability. In the CNC checking machines, it is only a matter of software.

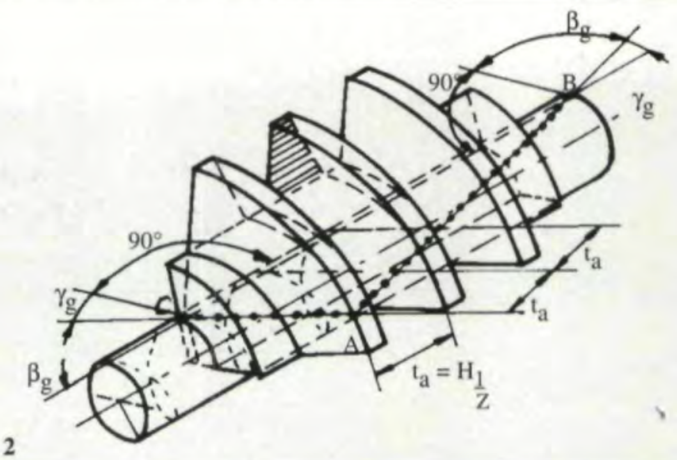

Fig. 2

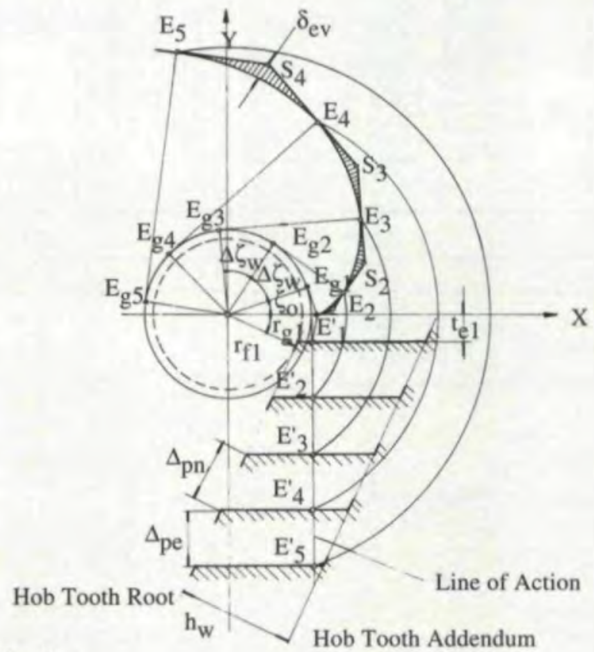

Fig. 3

The checking of the line of action or generation is made according to the graphic in Fig. 2, following the line AB. This line is held in a plane tangent to the base circle (radius rg) of the hob, because a hob for its involute profile, is equivalent to a worm or to a gear with a number of teeth equal to the number of starts.

Accordingly, this criterion in the graphic of Fig. 3 represents the hob's different cutting flanks and its correspondent positions in the gear tooth involute flank during the generation. The points we measure in the line of action, E1', E2', E3' .....etc., generate the involute in the points E1, E2, E3, ...etc., placed on the theoretical involute.

On the other hand, accordingly, the number of cuts, i.e., the number of the hob gashes and

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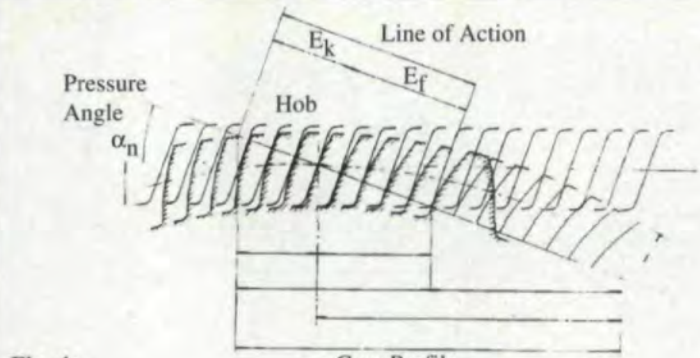

Fig. 4a

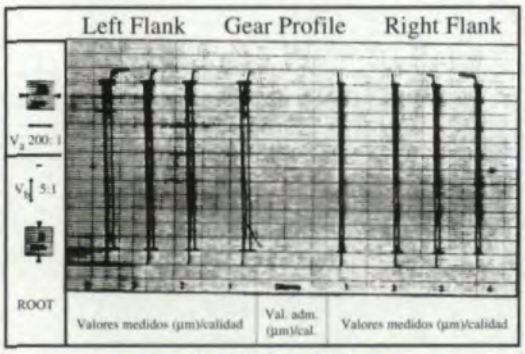

Fig. 4b Gear Profile Tooth Chart

Table I
Individual Hob Errors
(Numbered in accordance with DIN 3968)

	F_e^*
6 - Addendum eccentricity diameter runout	0%
7 - Cutting face error	7%
8 - No adjacent flute spacing error 9 - Adjacent flute spacing error 10 - Adjacent flute spacing error	7%
11 - Direction of blades (function of the module)	0.6%
12 - Deformation profile	100%
13 - Chordal thickness	94%
14 - Axial lead between consecutive cutting edges 15 - Axial lead in one turn	94%

$$F_e = F_e^* \cdot f$$

F_e = Error in one turn
F_e^* = Percentage of individual errors on error F_e.

Table II

	Module range	from to	0.63 1	1 1.6	1.6 2.5	2.5 4	4 6.3	6.3 10	10 16	16 25
16	Variation along line of action from tooth to tooth measured at cutting edge.	AA DIN	± 4	± 4	± 4	± 5	± 6	± 8	± 10	± 12
		ISO	± 4	± 4	± 4	± 5	± 5	± 6	± 8	± 11
		A DIN	± 6	± 7	± 8	± 9	± 10	± 12	± 16	± 20
		ISO	± 6	± 6	± 6	± 8	± 8	± 10	± 12	± 18
		B DIN	± 12	±14	±16	±18	±20	±25	±32	±40
		ISO	± 10	±10	±11	±13	±13	±17	±22	±32
		C DIN	± 25	± 28	±32	±36	±40	±50	±63	±80
		ISO	± 20	± 20	±22	±26	±26	±34	±45	±63
17	Cumulative variation of involute helicoid over active length.	AA DIN	8	8		10	12	16	20	25
		ISO	12	9	8 10	12	12	15	20	28
		A DIN	12	14		18	20	25	32	40
		ISO	14	14	16 16	19	19	24	32	45
		B DIN	25	28		36	40	50	63	80
		ISO	25	25	32 28	34	34	42	55	80
		C DIN	50	56		71	80	100	125	160
		ISO	50	50	63	70	70	85	110	160

the number of hob threads (starts), the error δev can be variable.

Finally, we can consider that the line of action errors are the result of the hob errors in the hob's lead, profile, index, and run-out.

Interpretation of the Line of Action Check

If we do not consider any kind of additional errors beyond the hob error, the involute profile generated by this hob should be identical to the hob line of action checked.

In Fig. 4a we show a typical checked hob line of action graphic, and in Fig. 4b, we show the gear profile obtained with this hob without machine errors, hob workholding errors, and without machine flexing.

Advantages. The check is independent of the number of hob starts because we are checking the final result of the generated gear.

We know what the gear's profile will be, and what will be affected by the hob on the gear profile quality. This will give the end user absolute assurance of the hob quality and generated gear profile.

In Table 1 we can see the percentage of the individual hob errors, which will have an influence on the line of action checked. As we can see, the main factors are lead and profile.

Control (Check) Standards. The only standards which include the hob line of action inspection are DIN 3968 and the ISO. All the other standards (AGMA, BS, MCTI, etc.) only have as an equivalent the checking of the lead in three revolutions (the maximum number of revolutions to generate an involute profile), but they do not include the hob profile errors. In Table 2 we show the inspection values according to DIN and ISO standards.

The standards, which include the inspection of the hob lead in three revolutions depends on the number of starts. So, for example a $\alpha n = 14° 30'$, the number of revolutions to be checked will be:

Z = 1 ———> 3 revolutions
Z = 2 ———> 1.5 revolutions
Z = 3 ———> 1 revolutions
Z = 4 ———> 0.75 revolutions

Conclusion. The checking of the line of action (generation) is the only one which guarantees the quality of the gear profile obtained by generation with the hob. We consider the line of action control as the most important for hobs in the complete inspection criteria of DIN and ISO standards. ■